ISTRY OF AGRICULTURE, FISHERIES AND FOOD

SHERY INVESTIGATIONS

es II, Volume 27, Number 5

xperiments on the culture of ne spot prawn *Pandalus platyceros* Brandt nd the giant freshwater prawn *Macrobrachium rosenbergii* (de Man)

HN F. WICKINS

eries Experiment Station, Conway

ONDON:
ER MAJESTY'S STATIONERY OFFICE 1972

© *Crown copyright 1972*

SBN 11 241085 5

Contents

ABSTRACT . . . . . Page v

INTRODUCTION vii

METHODS 1

Collection of parent stock 1

Quarantine, breeding stock and the collection of larvae . . . 1

Treatment of experimental animals 1

Experimental procedure 2

EXPERIMENTAL RESULTS—PART I *Pandalus platyceros*, LARVAE . 3

General 3

Temperature 3

Salinity 5

Condition of the culture media 5

Food 5

Large-scale culture of larvae 6

EXPERIMENTAL RESULTS—PART I *Pandalus platyceros*, POST-LARVAE 7

General 7

Food 8

Salinity and temperature 8

Growth and survival of populations of juveniles 9

Reproduction 10

EXPERIMENTAL RESULTS—PART II *Macrobrachium rosenbergii*, LARVAE 11

General 11

Culture requirements 11

Food 11

Large-scale culture of larvae 12

EXPERIMENTAL RESULTS—PART II *Macrobrachium rosenbergii*, POST-LARVAE 15

General 15

Salinity 15

Large-scale experiments 16

Reproduction 19

DISCUSSION 20

ACKNOWLEDGEMENTS 21

REFERENCES 22

Abstract

Some of the basic environmental requirements of two species of prawn, *Pandalus platyceros* Brandt and *Macrobrachium rosenbergii* (de Man), are described. Both species were cultured from the egg to a marketable size (8–10 g live weight) and some information was obtained on factors such as food, salinity, temperature and population density, which influenced their survival and growth rates.

In some experimental populations *P. platyceros* grew to 5–8 g in nine months and yielded 200–500 g of prawn per m^2 of tank floor. Survival was reduced by sudden changes in temperature, particularly above 20°C and below 9°C.

An experiment with *M. rosenbergii* showed that 1 g of seed prawns (mean weight 30 mg) yielded 151 g of prawns per m^2 of tank floor in three months when the population density was low (73 prawns per m^2) and that this was reduced to 23 g in crowded conditions (1 440 prawns per m^2). Specimens cultured in closed water systems readily matured and produced live larvae approximately 12 months after hatching.

Digitized by the Internet Archive
in 2025

https://archive.org/details/fishery-investigations-series-ii_1972_27_5

Introduction

The possibility of commercial prawn culture in Great Britain was introduced by the studies of Reeve (1969), Forster (1970a) and Wickins (1972) with the common prawn *Palaemon serratus* Pennant. Elsewhere in the world considerable effort has been applied to the cultivation of prawns. According to recent reports (Ryther and Bardach 1968, Mistakidis, 1968–1970), some of this effort was employed in the improvement of traditional methods—typically practised in the Indo-Pacific countries—while a proportion went into the development of new techniques. However, all the systems in operation or under consideration are in relatively warm climates and involve the use of outdoor ponds or tanks for fattening juvenile prawns.

In Britain the choice of a species of prawn that could be cultured in this way is restricted by the climate to the slow-growing temperate-water species. Of these, one of the most promising is believed to be the spot prawn *Pandalus platyceros* Brandt (see Plate 1), and in the first section of this report attempts to culture this species are described. In the second section, experiments in the culture of the giant freshwater prawn *Macrobrachium rosenbergii* (de Man) are reported (see Plate 2). This species is native to Malaysia and India and has qualities that are desirable in a cultured prawn. In particular it is known to breed readily in captivity and has a very rapid growth rate. Ling (1967a) states that pond-cultured specimens have grown from 0.5 to 110 g live weight in 7 months. However, since *M. rosenbergii* requires water temperatures of about 28°C its mass culture in Britain would only be feasible in an indoor environment.

The experiments reported in this paper were intended: (a) to provide an indication of the culture requirements of both species at all stages of their development; (b) to show if favourable qualities such as rapid growth could be induced in captivity; (c) to reveal aspects of their biology likely to be limiting; and (d) to highlight aspects of their culture requirements that might warrant more detailed research.

lethods

ection of parent stock

milar methods were used for transporting live ovigerous vns of both species to the laboratory. They were packed ealed polythene bags half filled with water, half with air xygen, and flown from British Columbia (*P. platyceros*) Hawaii (*M. rosenbergii*). Provided that they were ped in the pressurized holds of aircraft and did not er undue temperature fluctuations, the survival rates e good (>90 per cent). It was usually necessary to re-ve—or cover with a piece of rubber tubing—the sharp rum of each prawn so that the polythene bags were not ctured. On two occasions consignments of *P. platyceros* e received that had been packed dry (in "wood wool" expanded polystyrene "worms" respectively) to reduce ght charges. Mortality was higher in these shipments and vas possible that some broods of eggs were damaged ing their period out of water.

n arrival at London Airport the prawns were trans-ed to polythene bins containing 40 litres of water—at and 32‰ salinity for *P. platyceros* or 28°C and 2‰ for *rosenbergii*—and taken by road to the laboratory. ashing was reduced by baffles (in the form of a stack of f round PVC sheets held together by cords) placed at the tom of the bins. The journey lasted six to seven hours l during this time oxygen from a cylinder was bubbled ough the water to maintain a satisfactory level of dis-ved oxygen. Supplementary heating for *M. rosenbergii* s provided by a thermostatically controlled immersion ter; this was powered from a dynamo that was in turn from the battery of the transport vehicle. Prawns which e transported in this way survived well, and mortalities this part of the journey did not exceed 5 per cent.

arantine, breeding stock and the collection of larvae

t was thought advisable to keep imported adults of both cies in closed water systems so that adequate quarantine cautions could be taken. Any water or items of equip-nt that were associated in any way with the prawns were jected to a process of chlorination for 24 hours before y were discarded or re-used. By this means the risk of roducing foreign organisms was reduced.

Ovigerous specimens of *M. rosenbergii* were held in arate 25 litre tanks (48×28×25 cm deep) because of ir tendency to fight, and *P. platyceros* were held either arately—in 10 litre polystyrene aquaria (30×18×20 cm p)—or together in 400 litre fibreglass tanks (126×55× cm deep). The overflow from each large tank was directed o a small tank into which newly-hatched larvae passed l were collected (Wickins 1972).

atment of experimental animals

vae: Experiments with larvae were made in 1 litre hard ss beakers and 500 ml flat-bottom flasks. *P. platyceros* vae were cultured at concentrations of 1–25 per litre ker and *M. rosenbergii* at 50 per litre beaker and 1 per ml flask. In the text the terms larval density and concentration refer to the numbers per litre and have nothing to do with specific gravity. The terms post-larvae and juveniles are used to refer to stages a few weeks after metamorphosis. Generally two but sometimes three or four replicate populations were used in each experiment, and except where qualified in the tables the mean result of each set of replicates is reported.

Most of the experiments were made in the temperature range of 13–16°C for *P. platyceros* and 27–29°C for *M. rosenbergii*. The vessels stood either in water baths for temperature control, and in this situation they received some natural as well as continuous artificial illumination, or on shelves in a controlled temperature room, where they received only continuous artificial illumination.

Each day any dead food and larvae were removed with a pipette, and fresh food—newly hatched nauplii of *Artemia salina* L.—was supplied to maintain a concentration of 10–20 nauplii per ml. Three or more times each week the water and food in the vessels were renewed, except where detailed in the text.

Larger numbers of *P. platyceros* larvae were cultured in black polythene bins holding 60 litres of water and clear 10 litre polystyrene aquaria (30×18×20 cm deep); similar cultures of *M. rosenbergii* were made in 400 litre fibreglass tanks (126×55×61 cm deep). In three of the trials with *M. rosenbergii* (see below), many of the culture conditions were similar:

1. the temperature was controlled at 28 ± 1°C by an immersion heater and thermostat in each tank;
2. the tanks were half drained and refilled with clean water twice each week;
3. each day detritus was removed from the tanks by siphoning; newly hatched *Artemia* were added to maintain a concentration of 10–20 per ml in the water; suspensions of unicellular algae were also supplied.

The gentle aeration, which was supplied to all cultures, was sufficient to keep larvae and their food in suspension but it was not so vigorous as to prevent the larvae from catching their prey.

Post-larvae: Vessels in which post-larvae were held included fibreglass tanks (126×55×61 cm deep—400 litres, and 69×83×46 cm deep—250 litres); white polythene tanks (57×37×25 cm deep—50 litres, and 48×28×25 cm deep—25 litres); and 400 litre wooden tanks (120×120×30 cm deep) painted with two coats of a non-toxic brown paint. The fibreglass tanks frequently contained additional surface areas on which the prawns rested. There were usually three or four sheets of 5 mm mesh plastic suspended either vertically or horizontally in the water. They were arranged so that prawns could always swim around them and were not prevented from reaching any part of the tank.

Water: In the text natural sea water refers to water taken at high tide from the Conway estuary; some settlement of silt took place during its passage through storage tanks. Filtered water refers to natural sea water that had been passed through a plate filter containing diatomaceous earth which removed 90 per cent of suspended particles down to 2.5 μm in size.

P. platyceros was cultured throughout its life at salinities of 30 ± 3‰, but the requirements of *M. rosenbergii* differed in the larval and post-larval stages. Larvae were cultured in water of 10–15‰ salinity, post-larvae and juveniles at 1–2‰ and breeding adults at 2–5‰. The low-salinity water was prepared by mixing proportions of filtered sea water and Conway tap water.

An analysis of Conway tap water—Conway Valley Water Board, November 1970—gave the following results:

Appearance	clear and colourless
Odour	nil
Reaction, pH	6.4
Colour (Hazen units)	less than 5
Composition (parts per million)	
Total solids	27
Nitrogen as free and saline ammonia	0.00
Nitrogen as albuminoid ammonia	0.00
Nitrogen as nitrites	nil
Nitrogen as nitrates	less than 0.5
Chlorides, as Cl	7
Oxygen absorbed from permanganate in 4 hours at 27°C	1.9
Total hardness	11
Temporary hardness	8
Permanent hardness	3
Alkalinity	8
Total residual chlorine	nil
Free available chlorine	nil
Potassium, as K	0.2
Anionic synthetic detergents	–
Manganese, as Mn	–
Cyanides and thiocyanates	–
Poisonous metals	nil
Added chlorine	0.05 (approx.)

Food: Larvae were fed each day with the live nauplii of *Artemia salina* at a concentration of about 10–20 per ml. When slightly larger *Artemia* (*c.* 2.0 mm) were required nauplii were cultured for 24–48 hours in dilutions of the unicellular alga *Isochrysis galbana* Parke containing 500–1 000 cells per µl.

The most satisfactory food for juveniles and adults was found to be fresh mussel, *Mytilus edulis* L. In the text *Mytilus* flesh refers to this tissue, which was predominantly gonad; small pieces were fed to post-larvae but larger prawns were usually given the meat on freshly opened and separated shells of *Mytilus*.

Experimental procedure

The experiments reported in this paper were largely empirical, due to the exploratory nature of the studies. In some tests it was sufficient to know if the prawns would live under the experimental condition, and in this type of trial it was only necessary to use small numbers of animals. Other tests were made—in which growth as well as survival were measured—in order to judge the effects of more subtle factors and to indicate areas that seemed promising for further research. In the results, survival was expressed as a mean percentage value, to accommodate tests made with different numbers of animals; growth was measured in terms of increases in length and weight.

Measurements of length: Live larvae and post-larvae were measured with a low-power binocular microscope fitted with a graduated eyepiece. Specimens were placed in a drop of water on the stage and manipulated into an extended position with a fine paint brush, while the water was removed with a narrow-bore pipette. Measurements were made from the tip of the rostrum to the tip of the telson—excluding uropods. After measurement the larvae were washed back into the culture vessel. Conducted with care this procedure caused no apparent damage to the larvae. Live juvenile and adult prawns were measured by holding them against a graduated rule. This method was used in preference to the more precise method of Cole and Mistakidis (1953), since there was less risk of causing damage to the prawns and particularly to small, very active and newly moulted specimens.

Measurements of live weight: Individual prawns were removed from their containers with a mesh strainer and placed on several layers of absorbent tissue paper. A single piece of tissue paper was laid over the prawn, which was then gently stroked with a soft paint brush. This method removed most of the external water. The prawn was then placed in a tared box and weighed. A series of repeated test weighings showed that the method gave reasonably consistent results (Forster 1970b). Populations of prawns and specimens over 10 g were weighed to the nearest 0.5 g on a top-loading balance.

Experimental Results - Part I *Pandalus platyceros*, Larvae

General

The first-stage larva of *P. platyceros* hatches as a large, lightly coloured zoea (7.6–8.2 mm total length). Berkeley (1930) stated that hatching occurred at a more advanced stage of development than in other known British Columbian prawns of the same genus. Larvae cultured at Conway passed through four moults to complete their development in 15–29 days, and the frequency of moulting of 30 individuals that were cultured at 14±1°C is shown in Figure 1. The relationship between intermoult period and age was expressed by the regression equations:

$$A = 1.68\ I + 0.78$$

and

$$I = 0.25\ A + 2.92$$

where A=age at previous moult, in days; and I=intermoult period, in days. The average intermoult period increased from 4 to approximately 8 days as larval life progressed.

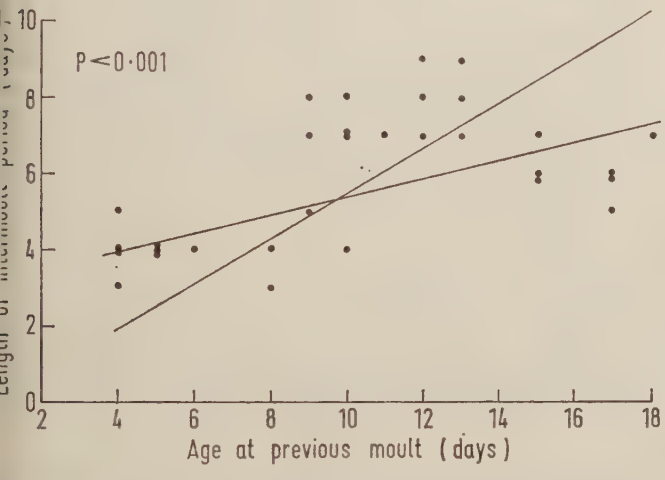


Fig. 1. The frequency of moulting of *Pandalus platyceros* larvae. The calculated regression lines are drawn.

The larvae propelled themselves by rapid movements of the natatory exopods, which were on the maxillipeds in stage 1 larvae and on the first three pairs of pereiopods in later stages. After the fourth moult they adopted the adult methods of locomotion and used the abdominal pleopods for swimming and the pereiopods for walking. In the text, therefore, the term metamorphosis refers to the changes which occurred at the fourth moult and when the larvae first showed certain adult behavioural traits, for example they readily accepted prepared or non-living foods. However, although the late larvae resembled adults from the behavioural standpoint, some of the larval appendages persisted, for instance the exopods of the pereiopods. These disappeared during the next two or three moults.

It was interesting to note that late larvae were often seen to rest on the floor of culture vessels with the dorsal side uppermost in a way that simulated the posture of adults. This behaviour was perhaps related to the abbreviated development of *P. platyceros*, since it was not characteristic of other species reared at Conway which passed through 10–11 stages before becoming post-larvae, e.g. *Palaemon elegans* Rathke, *P. serratus* and *Macrobrachium rosenbergii*.

Temperature

In their natural environment mature females and first- and second-stage larvae (Berkeley 1930) are found in 70–80 m of water at temperatures of 7–11°C (Butler 1964). Later larvae and early post-larvae frequent shallow water (4–6 m in depth) and will tolerate temperatures of 0–18°C.

The effect of temperature on developing eggs: Ovigerous females that were transported to Conway at 8°C were warmed to temperatures between 10.5 and 15.5°C in the laboratory in order to speed up the development of their eggs. In general larvae hatched earlier from females kept at the higher temperatures, but the results of the rearing trials made in 1969 and 1970 showed that from each consignment of imported females the first broods to hatch survived less well than those hatching later. It seemed likely that the temperatures encountered during the incubation period were having an effect on the subsequent viability of the larvae. The effect was highlighted when the differences between the percentage of larvae that metamorphosed during the first and second halves of three hatching periods were compared. The comparison was made using information from the control populations of 23 small-scale experiments to ensure that standard conditions of culture had been used; the mean duration of the hatching period was 50 days.

The mean differences were:

	First 50% of hatching period	Second 50% of hatching period
Number of larvae that hatched	344	196
Number of post-larvae that developed	66	101
Percentage of post-larvae	25%	60%
Mean percentage difference in the survival of post-larvae	35%	

The relationship between the proportion of post-larvae that developed from each batch of larvae and the temperature at which they had been incubated is plotted in Figure 2. The points show a tendency towards decreasing proportional yield of post-larvae with increase in incubation temperature but the calculated correlation coefficient ($R=-0.6563$, d.f. 4) was not statistically significant ($P>0.1$). The scatter of points in Figure 2 is thought to be due to the different lengths of time for which the eggs were subjected to the elevated temperatures. The incubation periods (27–120 days), the mean temperatures (10.5–15.5°C) and the mean percentage of post-larvae that developed (2.5–51.1 per cent) are shown in Table 1. It was possible that some of the eggs which were incubated at high temperatures for only short periods were not as seriously affected as others subjected to the same temperatures but for longer periods.

Price and Chew (1969) reported that eggs collected from ovigerous females of *P. platyceros* which were incubated at 11°C hatched later but produced better larvae than eggs held

TABLE 1 *The proportion of post-larvae of* Pandalus platyceros *which were cultured from eggs incubated at different temperatures for various lengths of time*

Date	Duration of incubation period (days)	Mean temperature (°C)	Number of larvae hatched	Number of post-larvae cultured	Percentage survival
8 Nov 1968	72	15.5	394	23	5.8
8 Nov 1968	105	12.0	439	39	8.9
8 Nov 1968	120	10.5	1 449	373	25.7
20 Mar 1969	27	13.0	1 251	398	31.8
6 Mar 1970	30	14.0	3 196	80	2.5
6 Mar 1970	45	11.0	3 366	1 719	51.1

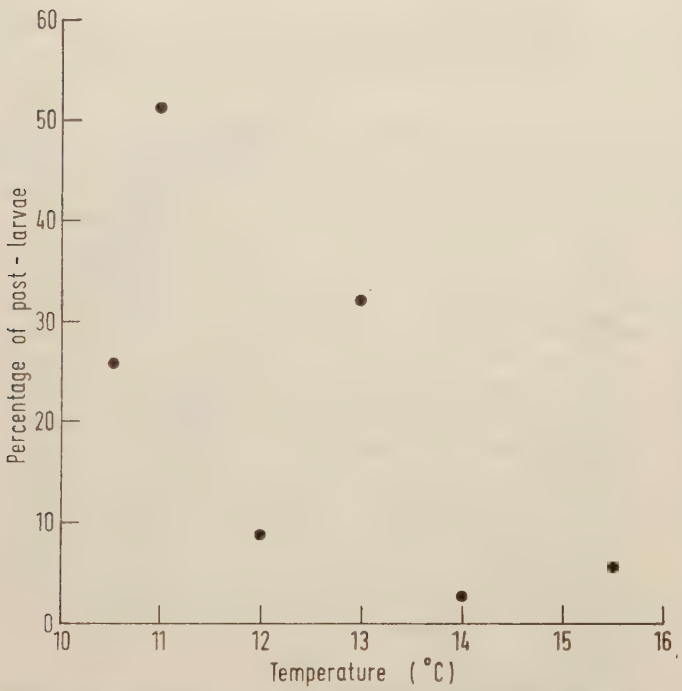


Fig. 2. The relationship between incubation temperature and the survival of *Pandalus platyceros* larvae to the post-larval stage.

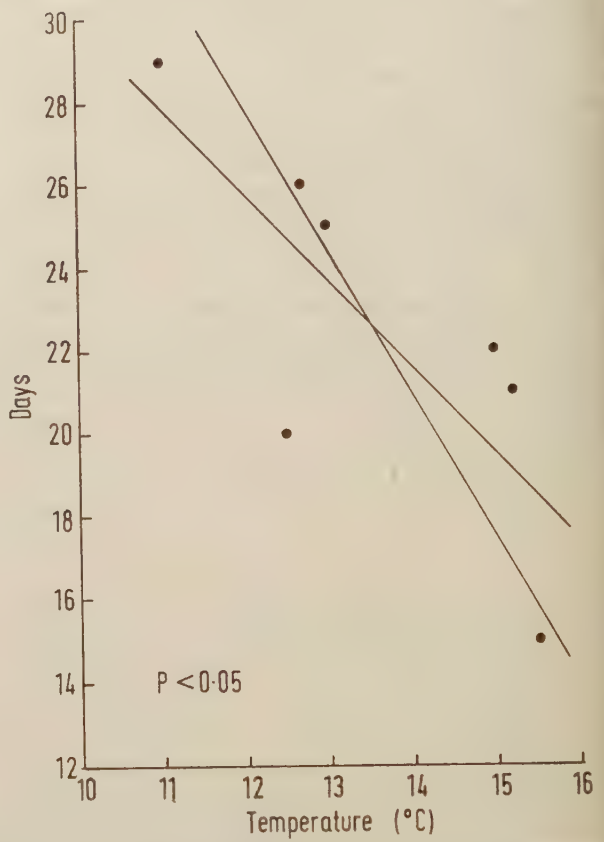


Fig. 3. The relationship between temperature and the duration of larval life of *Pandalus platyceros*. The calculated regression lines drawn.

at 13 or 15°C. Further indications that incubation temperature could affect the subsequent development of larvae were noticed when eggs of *Palaemon serratus* incubated at 15°C gave rise to fewer post-larvae than those that were held at 20°C (Wickins 1972). The results with *Pandalus* indicate that the eggs were adversely affected by the elevated temperatures used to bring forward the time of hatching.

The effect of temperature on larvae: Three batches of newly hatched larvae were cultured at temperatures between 11 and 15.5°C. Survival was good over the range tested and 69 per cent reached the post-larval stage. The results are shown in Table 2.

Larvae developed more rapidly at the higher tempe tures, and the regression ($P < 0.05$) of the length of the lar life on temperature is plotted in Figure 3. The length of larval life was defined as the age of the culture when 50 cent of the original larvae had become post-larvae. A sa factory rearing temperature for larvae was found to 14–15°C.

TABLE 2 *The effect of temperature on the survival and development of* Pandalus platyceros *larvae*

Expt.	No. of larvae per litre	No. of replicates	Temp. (°C)	Total survival % (larvae and post-larvae)	Post-larvae (%)	Age of culture when 50% were post-larvae (days)
A	5	2	13.0	90	80	25
			15.0	90	90	22
B	10	3	11.0	77	77	29
			12.5	73	73	20
			15.5	80	80	15
C	15	4	12.7	35	28	26
			15.2	15	26	21

inity

Larvae of *P. platyceros* were normally cultured in sea er of 30 ± 2‰ salinity. On occasions, for example when p tides followed a prolonged period of wet weather, the nity of the laboratory sea water fell to *c.* 26‰. It was essary to know if low salinities would seriously affect the vae, although the prolonged use of low salinity water in laboratory was not usual. Accordingly a test was made which four replicate populations of five larvae were cul- ed at 26‰ and 29‰. The larvae had hatched in a salinity 32‰ and were cultured through one moult in water of ‰ salinity before the test was started. After 24 days of ture 80–90 per cent had metamorphosed to become lthy post-larvae and there were no significant differences e to the treatments ($P > 0.05$).

The larvae used in the test were taken from an unknown mber of different broods—perhaps two or three—and hough it is possible that broods might respond differently eeve 1969), the results were taken to indicate that salinity riations of 26–29‰ were not likely to seriously impair val development.

ndition of the culture medium

Many of the attempts to culture *P. platyceros* were frus- ted by the erratic survival of broods of newly hatched rvae. The first ten days of larval life seemed to be the most itical and those larvae which survived this period usually ent on to complete their development. It was possible that me broods were weakened during incubation by the gours of transportation or by the laboratory environment ee above) and were perhaps more susceptible to disease.

In 1970 three tests (A, B and C, see Table 3) were made see if the survival of larvae was affected by differences in lture hygiene. Experiment A was made at a time when utine attempts to culture newly hatched larvae were giving or results—less than 25 per cent survived; however, by the time experiments B and C were made, contemporary broods were surviving well (60 per cent). The results of the tests have been combined in Table 3. In trials A and B larvae were cultured for nine days in the presence of 50 i.u. of penicillin G and 0.05 mg streptomycin sulphate per ml; this antibiotic mixture is known to be effective in reducing the activities of micro-organisms in sea water (Walne 1958). The medium used was filtered sea water and was renewed daily. The antibiotics improved the survival of larvae by 44 per cent in the first test but in trial B larvae survived equally well without antibiotics (79 per cent survival, compared with 86 per cent when antibiotics were used).

In the third trial, C, which lasted ten days, the value of filtering the sea water was tested. It was conceivable that the condition of weak larvae would deteriorate in the presence of the suspended matter and potential pathogens in natural sea water; on the other hand, filtration of the water might remove some material that would assist their survival. For this test, females bearing mature eggs were placed in either filtered or natural sea water, so that their larvae would hatch directly into the type of medium in which they were to be cultured. After they hatched, two replicate groups of 25 larvae from each female were cultured. An analysis of variance made on the results showed that the difference between the survival of larvae in filtered and natural sea water was significant ($P < 0.05$), and that larvae in filtered water survived better than those in natural sea water (81 and 64 per cent respectively).

The results of these three tests showed that larvae were sensitive to the presence of antibiotics and suspended matter in the sea water. The survival of broods thought to be weak was improved by the presence of antibiotics, and perhaps this was an indication that they were more susceptible to pathogenic micro-organisms in the water than other stronger broods. It was encouraging to find that 64 per cent of the *P. platyceros* larvae survived in the natural sea water at Conway, although their survival was improved (to 81 per cent) when the water was filtered.

ABLE 3 *The effect of two treatments, the presence of antibiotics and filtration of the sea water, on the numbers of* Pandalus platyceros *larvae that survived when <25% of contemporary broods were surviving (Experiment A), and later (Experiments B and C) when other broods were surviving well (60%)*

	Expt A: 25 larvae per litre		Expt B: 7 larvae per litre		Expt C: 25 larvae per litre	
	Antibiotics	No antibiotics	Antibiotics	No antibiotics	Filtered water	Natural water
plicate 1	20	6	5	5	19 23	20 14
plicate 2	15	7	6	7	19 20	15 15
ean percentage rvival	70	26	79	86	81	64

od

The nauplii of the brine shrimp (*Artemia salina*) have been dely used as a food for the larvae of caridean prawns, ther as newly hatched nauplii (Lewis and Ward 1965; ubschman and Rose 1969; Little 1969), one-day-old uplii (Broad and Hubschman 1963), or as nauplii supple- ented with suspensions of unicellular algae (Regnault 69, Fujimura and Okamoto 1970, Wickins 1972).

Preliminary trials with *P. platyceros* showed that the first stage zoeae were able to catch and eat both newly hatched (0.6 mm total length) and partially grown (2.0 mm) *Artemia*. It was possible that the larvae would find small nauplii difficult to catch and might therefore grow better if larger prey were available. Four experiments were made to compare more critically the food value of the two diets in terms of their effect on the growth and survival of larvae.

TABLE 4 *A comparison of the survival and growth of* Pandalus platyceros *larvae fed with newly hatched and partially grown* Artemia salina

Brood	No. of larvae per litre	No. of replicates	Diet of newly hatched *Artemia*, mean length 0.6 mm			Diet of grown *Artemia*, mean length 2.0 mm		
			Survival (%)	Mean length (mm) of		Survival (%)	Mean length (mm) of	
				8-day-old larvae	post-larvae		8-day-old larvae	post-larvae
A	6	2	33			8		
B	12	2	50			29		
C	1	10	90		12.8	80		13.0
D	10	2	65	8.9	11.0	65	9.2	11.0

The results of each test are given separately in Table 4, since two of the broods of larvae that were used (A and B) did not survive well and 50 per cent or less reached the post-larval stage. The two remaining broods (C and D) gave better results and 65–90 per cent completed their development. The mean sizes of larvae and post-larvae from broods C and D were compared but no significant differences were found according to the diets they had received ($P > 0.05$). Brood C post-larvae were significantly larger ($P < 0.05$) than those of brood D and had been cultured individually instead of in groups of ten larvae. It is not known whether the disparity in size was of genetic origin or was influenced by the different culture conditions. The results showed that neither the survival nor the growth rate was significantly improved by the diet of grown (2.0 mm) *Artemia* and that the newly hatched nauplii were a satisfactory food.

When larvae were deprived of food, cannibalism was frequently observed. The ability of larvae to prey on each other indicated that they might be able to utilize worms of the genus *Lumbricillus* (Oligochaeta, Enchytraeidae) as a food source. Previous work had shown that the smaller larvae (3.5–7.0 mm) of *Palaemon serratus* did not survive well on this diet and were often smothered by the worms (Wickins 1972). There was a possibility that the larger larvae of *P. platyceros* (7.6–10.0 mm) would be more successful in manipulating the worms. However, tests showed that this was not so and only 1 of 36 test larvae reached the post-larval stage on this diet, compared with 16 which completed their development on a diet of *Artemia*.

Large-scale culture of larvae

The first attempts to rear large numbers of larvae (100–1 000) were made in 1969 in polythene dustbins holding 60–65 litres of water, using techniques which had proved satisfactory for the culture of *Palaemon serratus* larvae (Wickins 1972). However, the results with *P. platyceros* were disappointing, because few larvae reached the second stage of their development and none moulted three times. Other trials made in smaller vessels—50 litre polythene tanks, 11 litre polystyrene aquaria and 3 litre glass beakers—gave better but somewhat erratic rates of survival; 5–57 per cent (mean 27.5 per cent of 1 567 newly hatched larvae) became post-larvae (Wickins 1969). Many of the broods used in those trials had experienced temperatures greater than 12°C during incubation and were possibly weaker as a result (see above). In 1970 better survival rates (23–94 per cent, mean 46 per cent) were obtained from broods that had been incubated at 11°C. These were reared in clear polystyrene aquaria in about 7 litres of water. They were fed with *Artemia* nauplii and transferred to clean media—filtered sea water—twice a week. Sufficient aeration was supplied to keep the larvae and their food in suspension. Altogether 1 041 post-larvae were reared from 2 274 larvae, and in Figure 4 the relationship between the initial population density—the number of larvae per litre—and the percentage that metamorphosed is shown. The proportional yield of post-larvae decreased as the initial concentration of larvae increased and the regression was significant ($R = -0.7951$, $P < 0.02$). It is interesting to note that a survival of 50 per cent corresponded with an initial concentration of approximately 30 larvae per litre with *Pandalus platyceros* and about 60 per litre with the smaller *Palaemon serratus* larvae (Wickins 1972).

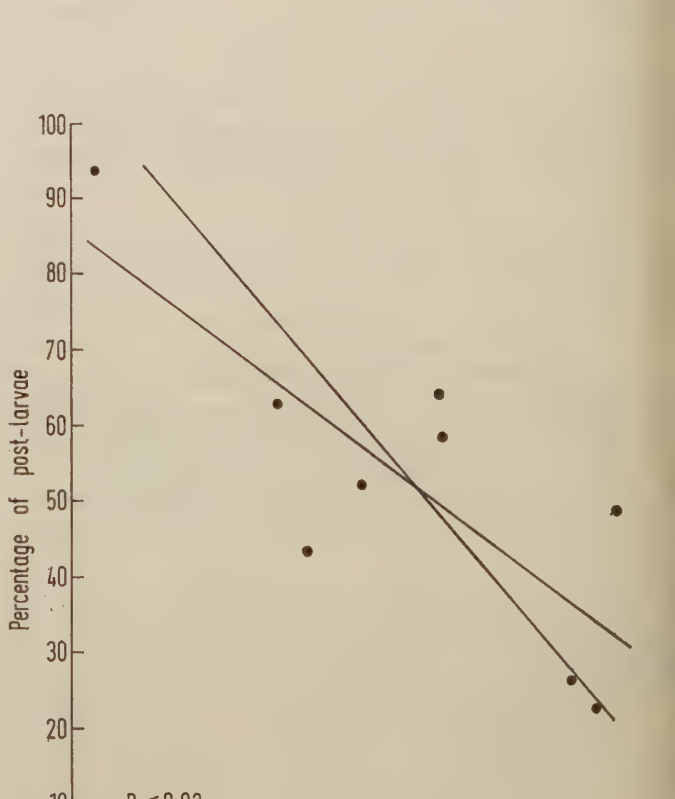


Fig. 4. The relation between the initial numbers of *Pandalus platycero* larvae and the proportion of post-larvae that developed. The calculate regression lines are drawn.

xperimental Results - Part I
'andalus platyceros, Post-Larvae

ıeral

mmediately after metamorphosis the young post-larvae 'e fed a decreasing amount of *Artemia* nauplii each day l a gradually increasing proportion of *Mytilus* flesh. After ɔroximately one week their "weaning" was complete and y were able to take larger pieces of the prepared food.

During the period of experimentation with *P. platyceros* ɔut 100 post-larvae were cultured in individual containers a diet of *Mytilus* flesh. These were inspected daily for ɔult-casts and were periodically weighed and measured. eir frequency of moulting is plotted in Figure 5 and shows increase in the intermoult period with the age of the ıwns—from 5 days at 3 weeks of age to 37 days after nonths. Some points of the graph show very long inter-ɔult periods which cannot be explained with the informa-n available. Since prawns were seen to eat their exuvia, ere was a possibility that some were completely eaten, us causing the record of a moult to be lost; if so, the corded intermoult period would be approximately twice expected duration. The relationship was described by the regression equations:

$$I = 0.13\ A + 2.29$$
$$\text{and } A = 5.24\ I + 8.86$$

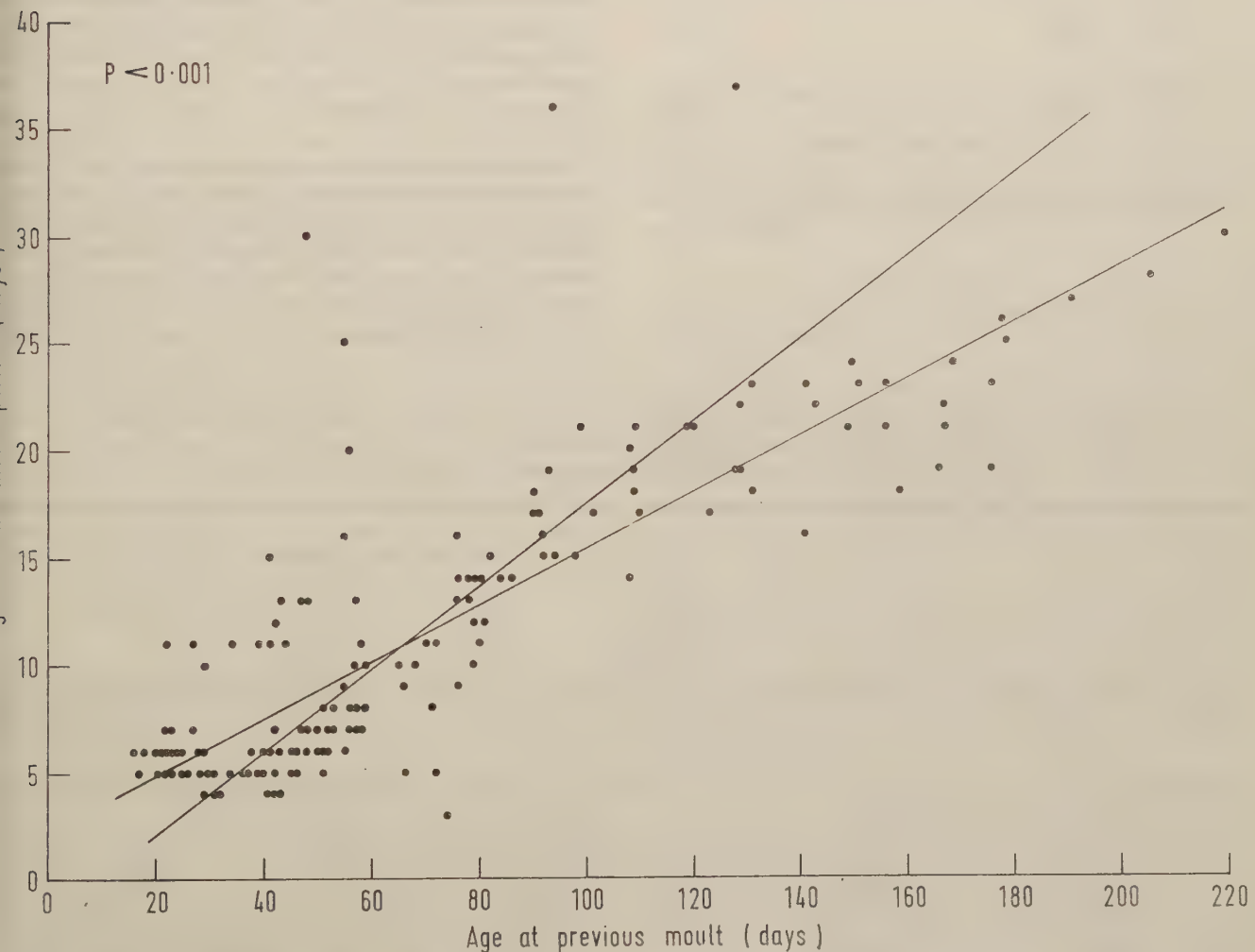
where I=intermoult period, and A=age at previous moult, in days.

In Figure 6 the relationship of total length—including the rostrum—and total live weight is presented. The information was plotted against logarithmic co-ordinates to give a linear relationship. The regression equations for the straight lines were calculated to be:

$$\log_{10}W = -4.90 + 2.86 \log_{10}TL$$
$$\text{and } \log_{10}TL = 1.71 + 0.35 \log_{10}W$$

where W=live weight in g and TL=total length in mm.

P. platyceros is a protanderous hermaphrodite and transition to the female form occurs after about two to three years of growth. Butler (1970) stated that, after the sex change occurs, the growth of the rostrum relative to the carapace decreases and the rostrum subsequently accounts for a decreased proportion of the total length. He calculated the total weight to carapace length relationship for prawns



g. 5. The frequency of moulting of juvenile *Pandalus platyceros*. The calculated regression lines are drawn.

up to four years old (Butler 1964) and obtained:

$$\log W = 2.93 \log CL - 3.08$$

where W=total weight in g and CL=carapace length in mm. In the present work only young prawns were used and the rostrum was included in the length measurements.

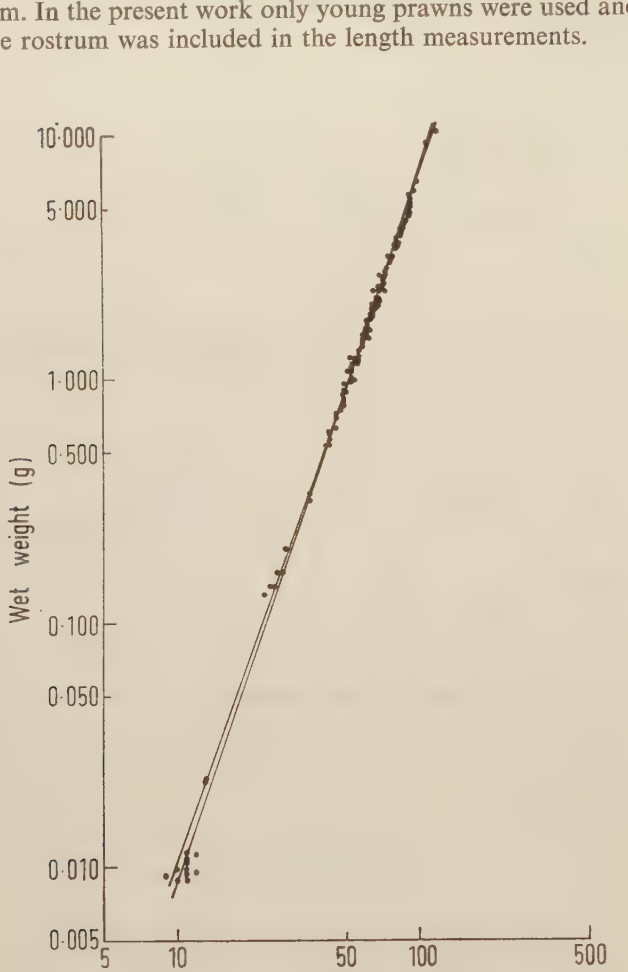


Fig. 6. The relationship between total length and live weight of juvenile *Pandalus platyceros*. The calculated regression lines are drawn.

Food

There was no difficulty in finding an acceptable food f *P. platyceros*. The post-larvae readily ate small pieces *Mytilus* flesh, frozen shrimp (*Crangon*), live worms of tl genus *Lumbricillus*, and a compounded diet (Forster 1970 consisting largely of Norwegian shrimp meal. *Mytilus* fles was proved to be a satisfactory food for *P. platyceros* whe post-larvae grew from 9 mg to 5 g in their first year culture; it was thereafter used as a standard diet.

Salinity and temperature

The vast majority, if not all, of the Pandalidae are marin stenohaline prawns and are reported to be particular sensitive to salinity changes (Panikkar 1968). According t Butler (1970) the post-larvae of *P. platyceros* remain i shallow water—from the sublittoral zone to about 55 m depth—until the end of their first year, when they migrat to deeper waters. It is possible that since they are able t inhabit coastal waters, juvenile *P. platyceros* will posses some degree of tolerance to a range of salinity and tem perature.

An experiment was made to test the effect of three sali nities (22‰, 26‰ and 30‰) and three temperatures (15, 1 and 20°C) on the growth and survival of young prawns. Five individual animals (mean weight 40 mg) were used i a factorial experiment which lasted 28 days. Each day th prawns were given fresh food—*Mytilus* flesh—and twice pe week they were transferred to clean filtered sea water. Befor the trial began each group of prawns was acclimatized to th experimental conditions over a four-day period. The result were expressed as the mean percentage increase in weigh made during the trial and are given in Table 5, together wit the numbers that survived.

Analysis of the results revealed that the effect of salinit on the growth of the prawns was more pronounced than th effect of temperature. A temperature of 20°C was unsuitabl for the prawns, particularly in conjunction with the lo salinity (22‰), where only two of the five prawns survive the 28 day period. All the prawns cultured at 26–30‰ an 20°C survived, although their growth rate was retarded.

TABLE 5 *The effect of salinity and temperature on the growth (expressed as the mean percentage increase in weight) of juvenile* Pandalus platyceros
Figures in parenthesis were the numbers surviving from each group of five prawns

Salinity (‰)	Temperature °C		
	15	18	20
22	63.5 (4)	100.2 (4)	65.9 (2)
26	201.1 (5)	272.1 (5)	90.1 (5)
30	205.5 (4)	360.0 (5)	151.9 (5)

An analysis of variance on the growth data gave:

Source of variation	Sums of squares	d.f.	Mean square	F ratio	P
Salinity	41122.2708	2	20561.1	7.9	<0.05
Temperature	30535.5034	2	15267.8	5.8	<0.1>0.05
Residual	10441.0544	4	2610.26		
Total	82098.8288	8			

concluded that the optimum salinity and temperature es were not less than 30‰ and about 18°C respectively.

e effects of extreme temperatures: Some information on ffects of extreme temperatures was obtained during two npts to culture prawns outdoors. In the first trial, popu- ns of small prawns (mean weight 0.4 g) were cultured n July 1969 to January 1970 in tanks containing flowing water to a depth of 15 cm. They were protected from ct sunlight by green painted plastic covers. During the ure period the temperature of the water in the tanks ged from 13–24°C (mean 18.5°C) in the hottest month)–8°C (mean 3.8°C) in December and January. The wns grew well under these conditions and after six nths 73 per cent of the original 200 prawns remained e and had reached a mean weight of 4.9 g. At this time, vever, many of the prawns showed symptoms similar to se of the mycotic disease previously observed in *Palaemon atus* by Anderson and Conroy (1968) and died during next four to eight weeks. Infected prawns, which were found smaller than 75 mm total length, frequently wed signs of severe damage to pleopods and uropods t were characterized by thick black areas in the cuticle rounded by a zone of reddening. Microscopic examina- n of the tissue showed extensive ramification of fungal phae. It was possible that the stress caused by low tem- atures had reduced their resistance to pathogens—per- ps a fungus—present in the sea water or food. Later, wever, in 1970 the same syndrome was seen in prawns red at 13–20°C (see below) but again only large prawns— er 75 mm total length—were found affected. An alter- tive possibility was that the long intermoult period of the ge prawns (more than 30 days) allowed pathogens a nger time in which to colonize and penetrate damaged eas of the cuticle.

In the second outdoor trial, beginning in July 1970, awns were cultured in the same tanks and depth of water t were supplied with sea water which was recirculated om a large shallow reservoir. During the first three weeks e heat of the sun quickly warmed the water in the reservoir d gave rise to prolonged periods of high temperature 20°C) in the experimental tanks. The immediate effect this was a high mortality rate (45 per cent) among the awns. Continuous records showed that the water tem- rature ranged from 14–25°C (mean 20.3°C) and that the awns were subjected to temperatures higher than 20°C for , 154 and 44 hours in each week respectively. By com- rison, prawns reared in the previous trial experienced mperatures of over 20°C for only 38, 7 and 38 hours during e hottest weeks. Although the evidence is limited it is nsidered probable that the prawns were killed by the gh temperatures. An experiment confirmed that cultured *platyceros* would not survive for more than seven to eight ys at a constant temperature of 23°C.

The growth of the prawns in this second trial was less an was expected. Their mean weight in July, three months ter hatching, was only 0.3 g, compared with a population equivalent age that had been cultured at 17 ± 2°C and hich weighed 1–2 g. It is worth mentioning that when the rvivors were moved to a more favourable environment e growth rate improved (see Figure 7, curve D). Previous ork with *Palaemon serratus* showed that juveniles which ad actually decreased in weight following a period of ress (induced, in that instance, by starvation) also re- overed rapidly to grow at the same rate as control prawns hen the stress was removed (Wickins 1972).

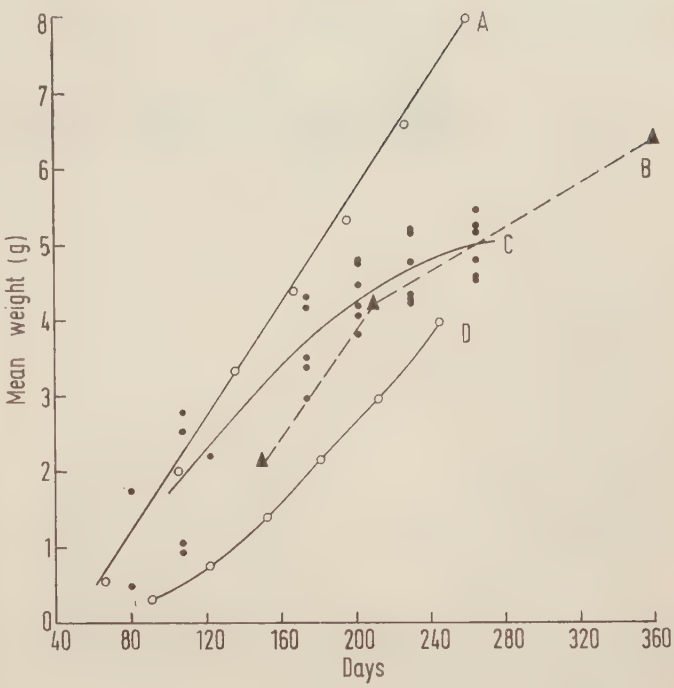


Fig. 7. The growth rate of cultured and natural populations of *Pandalus platyceros*. For explanation of the curves, see text.

Growth and survival of population of juveniles

Growth rate is one of the most important considerations which govern the choice of a species to be cultured. Among prawns, those species that reach a marketable size (i.e. 8–10 g live weight) in the shortest time are likely to be the most desirable.

Butler (1964) gave the mean size of natural populations of *P. platyceros* as 2.1, 4.2, 6.4 and 12.7 g at 5, 7, 12 and 17 months of age respectively. These figures, which were the average wet weights of captured prawns, were used as a base line with which the growth rates of cultured populations were compared.

Figures 7 and 8 show the growth and survival rates respectively of eight populations, containing 28–143 prawns, reared at Conway during 1969 and 1970. In Figure 7 the growth curve of a natural population (curve B) has been included for reference (Butler 1964). The mean weight of the live prawns was plotted against their age, in days, from hatching, and, in both natural and cultured populations, hatching occurred during springtime (March–April). The flattening of curve B after 200 days was estimated to coincide with the migration of juveniles to deep water and with the onset of winter and low water temperatures. Curves A and D show the growth of two populations (of 28 and 94 prawns respectively) which hatched in April 1970, and the points associated with curve C represent the mean growth of six populations (of 30–143 prawns) which hatched during April 1969. All of the cultured animals received a diet of fresh *Mytilus* flesh daily and were weighed at monthly intervals.

Prawns represented by curve C followed the same general trend as the natural population (curve B) and showed a decrease in growth rate that could be related to a drop in water temperature. Before day 200 the temperatures ranged from 13–20°C (mean 15.6°C) and afterwards from 5–16.5°C (mean 9.8°C). The drop in temperature was thought to be responsible for the reduced growth rate of the populations.

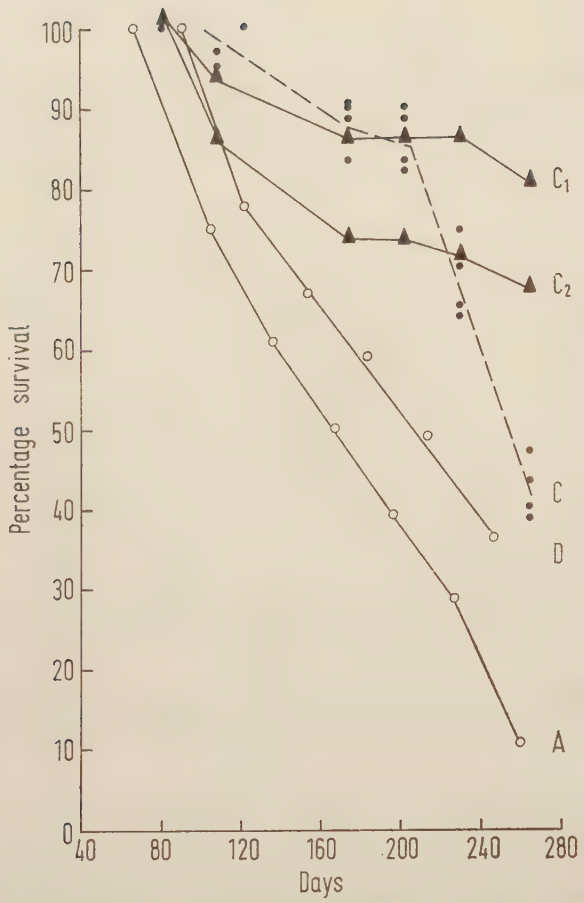


Fig. 8. The survival rates of cultured populations of *Pandalus platyceros*. For explanation of the curves, see text.

One noticeable feature of the graph is the difference between the curves A and D. The population denoted by curve D has been mentioned in this paper already (see the section on the effects of extreme temperatures); these prawns were stressed by prolonged exposure to high temperatures during early post-larval life. The prawns of group A, on the other hand, had not been subjected to such adverse conditions. Both groups were cultured under the same conditions for 160–200 days, during which time they grew well; their mean weight increase was 0.22 g per week. However, the weight increase of population A was slightly greater—0.26 g per week—than that of population D, which was 0.175 g per week. Whether or not this difference was related to the previous history of the animals is a matter of conjecture.

The survival rates of the populations are shown in Figure 8. The information given differs from that in the preceding graph by the absence of figures for wild prawns, and by the separation of the data of two populations from the composite curve C. These were the only populations to be reared outdoors in 1969 and are represented by curves C1 and C2.

The exploratory nature of these trials and the variety of habitats that were provided prevent any statistically valid quantitative statements being made on the relationships between survival and environmental factors such as population density. Nevertheless, in Appendix 1 information on the culture conditions of the eight groups is given. Some observations on the probable causes of mortality among the prawns may be usefully considered.

Population density: Mortality in populations of cultured prawns can often be directly related to the number of prawns per unit area of tank floor (Forster 1970a, Wickins 197 but in the present study, when the data from all ei populations were considered together, there was no corre tion between survival and population density. This indica that some other factors more profoundly influenced mortality rate. However, it was true that population C which contained 50 prawns per m², survived better duri the early part of the trial than population C2, which co tained 99 per m²; these populations were comparable, sir their only difference was the initial population density.

Temperature: It was stated earlier that the flattening of t growth curve C in Figure 7 was due to a drop in tempe ture; this was also thought to have been responsible for t sudden increase in mortality rate at day 200 shown Figure 8, curve C. Populations C1 and C2 also experienc the same low temperatures but the actual drop was mo gradual for these and occurred over a period of 2–3 wee rather than 2–3 days, as in the remaining four groups curve C.

Other causes: Throughout the experimental period the occurred steady losses of prawns from groups A and which could not be satisfactorily explained. It was like that cannibalism played a part, although soft partially eate prawns were seldom found. During the last two month moribund prawns infected with fungus were taken fro group A but fewer were seen in group D.

The overall results of the attempts to rear juvenile *P. platyceros* were very encouraging, particularly in terms o their rapid growth rate and lack of rigid environmenta requirements. Most of the prawns reared grew to an edibl size, *c.* 5 g, in one season—seven months—and three indi viduals reached 8 g in nine months. Indications tha mortality during the growing season could be caused b sudden temperature fluctuations and possibly diseases wer also obtained.

Reproduction

No information on reproduction was obtained, largel because the prawns were not cultured long enough fo females to develop. Imported females showed no signs o ovary development within six months of hatching broods o larvae. Butler (1970) mentions that there was no evidenc that the prawn breeds more than once a year and that ver few females from Vancouver Island breed more than onc in their lives. He gives the number of eggs carried by female of 33.5–41.4 mm carapace lengths as 1 393 to 3 162 egg per female.

Experimental Results - Part II
Macrobrachium rosenbergii, Larvae

General

The first-stage larva of *M. rosenbergii* hatches from the g as a small zoea of about 2.0 mm total length. It passes rough a variable number of moults—from 11 as reported Uno and Kwon (1969) to 13 according to Ling (1969a)— become a post-larva after 27–44 days. The basic environental requirements of larvae have already been described Fujimura (1966) and Ling (1969b). The experiences of ese authors were successfully employed in the present udy and have also been used elsewhere, for example in pan by Uno and Kwon (1969), and allowed a successful d commercially promising large-scale culture technique be developed in Hawaii (Fujimura and Okamoto 1970).

ulture requirements

A series of preliminary tests in which larvae were cultured 1 litre beakers showed that they survived equally well— 0 per cent in each test lived for 23 days—in sea water iluted with either deionized or domestic tap water at salities between 5 and 26‰. Temperatures of $28 \pm 1°C$ were tisfactory for development but the loss of water, by evaoration, from the experimental beakers was substantial; pproximately 20 ml was lost from 1 litre every 24 hours. hese losses were reduced in later tests when narrowecked flasks plugged with cotton wool were used.

The high temperature created special problems in smallcale cultures; these were associated with the high mortality ate of food organisms (*Artemia* nauplii) which, at 28°C, apidly used up their yolk reserves and died within 48–72 ours of hatching. Unless the media and food were renewed ach day, quantities of dead nauplii and associated microrganisms accumulated in the cultures. In these conditions ew larvae developed to the post-larval stage; better results ere, however, obtained from the mass cultures described elow.

ood

Uno and Kwon (1969) cultured the larvae of *M. rosenergii* on a diet of live *Artemia* nauplii. Fujimura (1966) and ing (1969b), however, stressed the value of rearing larvae cultures containing *Artemia* nauplii, ground fish flesh and ense suspensions of plankton called "green water", alhough neither author specified the latter's composition.

Two tests were made to see if larval growth was affected y the presence of unicellular algae. In the first test two eplicate populations of 50 larvae were cultured in 1 litre eakers; in the second, 7 replicate larvae, for each treatment, ere kept individually in 500 ml flasks. In each case the oncentration of food organisms (*Artemia* nauplii) was 0–20 per ml. The four species of algae that were tested and he concentrations at which they were initially present in he cultures were:

Species	Initial concentration (cells per µl)
Chlamydomonas coccoides Butch. (Chlorophyceae)	50
Skeletonema costatum (Greville) Cleve (Bacillariophyceae)	50 and 100
Isochrysis galbana Parke (Haptophyceae)	500
Tetraselmis suecica (Kylin) Butch. (Prasinophyceae)	200 and 600

The results are shown in Table 6 but since the larvae were cultured under different conditions the results of each test were kept separate (Table 6, A and B). Differences in the growth of the two control groups were likely to have been due to the different methods of culture; larvae kept individually and transferred to fresh media and food each day (B) grew more quickly than those in populations which were changed twice each week (A).

In Table 6A larvae cultured for 23 days in the presence of 500 cells per µl of Isochrysis and 600 cells per µl of *Tetraselmis* were larger (5.3 and 5.4 mm total length respectively) than those fed with *Artemia* alone (3.5 and 3.8 mm total length). Larvae grown in a suspension of 200 cells per µl *Tetraselmis* measured 4.8 mm but were not significantly larger than the controls ($P < 0.1 > 0.05$). The presence of *Skeletonema* significantly ($P < 0.05$) retarded development at the higher concentration used (100 cells per µl) and was associated with higher mortality rates (80 per cent) among larvae compared with the controls (30 per cent). Larvae grown in the presence of 50 cells per µl of *Chlamydomonas* (Table 6B) reached an average length of 5.6 mm in 24 days and were not significantly different in size from the *Artemia*-fed controls (5.7 mm). In the same test starved larvae and larvae cultured in a suspension of 50 cells µl of *Chlamydomonas*—without *Artemia*—fared equally badly and died within ten days of hatching. The majority (60 per cent) moulted twice and were recognizable as stage 3 larvae at the time of death; the rest moulted once to reach stage 2.

The tests confirmed that high concentrations of some species of algae—*Isochrysis* and *Tetraselmis*—could improve larval growth. A suspension containing 50 cells per µl of *Chlamydomonas* did not have any food value for the newly hatched larvae, neither did a suspension of this cell density improve a diet of *Artemia* nauplii.

The beneficial effect of the *Isochrysis* and *Tetraselmis* might be due to the larvae ingesting—either accidentally or actively—quantities of algae with their prey (*Artemia*) or, alternatively, might result from the better nutritional value of the *Artemia* which had consumed algae after their yolk reserves were depleted. A third possibility is that the fed *Artemia* survived longer and did not die in sufficient numbers to cause fouling in the cultures.

TABLE 6 *The effect of unicellular algae on the growth of the larvae of* Macrobrachium rosenbergii *fed with* Artemia *nau*
A. *Population of 50 larvae per 1 litre beaker, two replicates per treatment; results after 23 days*

Species of algae	Concentration (cells per μl)	Percentage of larvae surviving		Mean total length (mm) of larvae	P
		Replicate a	Replicate b		
Control	–	82	8*	3.5	
Isochrysis galbana	500	88	92	5.3**	<0.05
Control	–	70	70	3.8	
Skeletonema costatum	50	16	24	3.5	
,, ,,	100	10	20	3.3**	<0.05
Tetraselmis suecica	200	96	34*	4.8	<0.1>0.0
,, ,,	600	24*	88	5.4**	<0.05

* Denotes mass mortalities, cause unknown.
** Denotes mean length significantly different from that of the control populations.

B. *Seven individually held larvae per treatment. Two experiments; results after 24 days*

Experiment number	Control—no algae		95% limits	50 cells per μl of *Chlamydomonas*		95% limi
	Number of larvae surviving	Mean total length (mm)		Number of larvae surviving	Mean total length (mm)	
1	5	6.0	5.34–6.65	6	5.9	5.60 6.27
2	7	5.4	5.08–5.69	5	5.4	4.66 6.25
Mean		5.7			5.6	

Large-scale culture of larvae

During 1969 and 1970 four attempts were made to rear stocks of post-larvae for laboratory experiments. Three of these were moderately successful and are described in Table 7; the fourth failed after three days of culture when most of the larvae died. The cultures were made in fibreglass tanks in about 390 litres of water. Mortality occurred in the fourth trial when newly hatched *Artemia* nauplii were accidently put into the culture vessel before the salinity of the water was raised from 2‰—at which the larvae hatched—to 10‰, the salinity at which they were to be cultured. The combination of high temperature and low salinity caused the death of the nauplii during the following night and the resultant decomposition of their bodies was thought to have caused the death of the larvae.

Although many of the culture conditions in the successful trials were similar (see section on Methods) there were also some specific differences (see Table 7). In trial 2 the water was recirculated through a pebble filter and passed an ultraviolet lamp; and in trial 3, it was necessary to use a stock of *Artemia*—from Utah, U.S.A.—that was normally considered unsuitable as food for larvae (Bookhout and Costlow 1970). The Utah *Artemia* were, however, a satisfactory diet under the conditions of culture used, perhaps because of the continuous presence of algae; Utah *Artemia* only became a good food for larvae of *Palaemon serratus* after they had consumed an amount of algae (Wickins 1970). In the first two trials suspensions of *Isochrysis* and *Tetraselmis* were added to supplement the *Artemia* in an attempt to simulate the "green water" of Fujimura and Okamoto (1970), but in the third, cultures of *Chlamydomonas* were supplied to improve the food value of the Utah *Artemia*. The quantities algae that were added each day were not constant and varie according to the amount that could be obtained from th laboratory cultures. In Table 7 the total amounts added a averaged and expressed as the mean quantities given eac day.

The salinity in trials 1 and 2 was 10‰ but this wa increased to 12‰ on day 25; in trial 3 the salinity was 2 on day 1; it was increased from 5–7‰ on day 2 to 26‰ o day 13 and then gradually decreased to 15‰ on day 4 This provided more favourable conditions of higher salinit for the *Artemia* and algae and was thought to have reduce mortality amongst them.

The variety of conditions that were employed and th similar results obtained from each trial highlighted th natural toughness of the larvae. The results were e couraging in that 27 per cent of 48 000 larvae developed the post-larval stage when cultured at initial densities 39–46 per litre. For comparison, Fujimura and Okamo (1970) reared 21 per cent of 1 000 000 larvae to the pos larval stage in 18 927 litre tanks stocked initially with larvae per litre, and estimated the production cost of 1 0 post-larvae to be $1.93 (U.S.).

TABLE 7 *The production of post-larvae from large-scale cultures (400 litres) of* Macrobrachium rosenbergii *larvae. Larvae in trials 1 and 2 were fed with* Artemia salina *from California stocks, those in trial 3 received* Artemia *from Utah, U.S.A.*

	Trial 1		Trial 2		Trial 3
Initial number of larvae	15 000		15 000		18 000
Number of post-larvae	4 260		5 300		3 950
Percentage of post-larvae	28		35		22
Age of population when 95% had metamorphosed (days)	34		39		44*
Species of algae used	*Isochrysis*	*Tetraselmis*	*Isochrysis*	*Tetraselmis*	*Chlamydomonas*
Mean cell count (cells per μl)	10 260	1 600	10 260	1 600	3 000
Mean quantity added daily (litres)	4	6	4	6	6

* Age of population when 70% had metamorphosed.

xperimental Results - Part II
Macrobrachium rosenbergii, Post-Larvae

neral

mmediately after metamorphosis post-larvae were eaned" from a diet of *Artemia* nauplii to one of *Mytilus* sh. When this was accomplished they were acclimatized almost fresh water—salinity 2‰—to simulate the migran up rivers and streams that occurs among wild prawns.

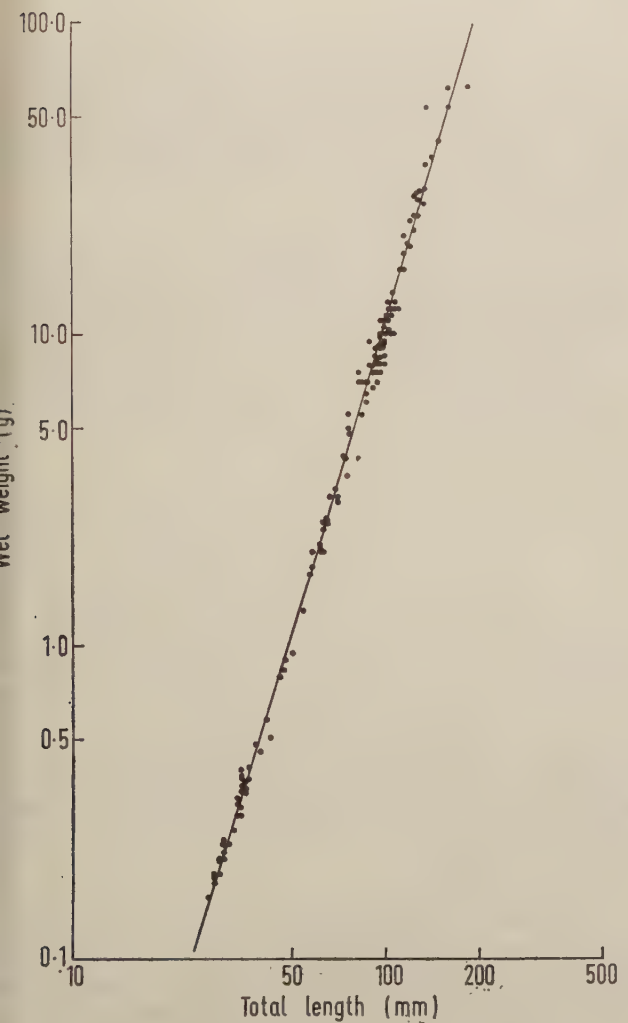
Approximately 70 prawns cultured in the laboratory were riodically weighed and measured to establish the relationp between total length and live weight. The results are own in Figure 9 where the length (from the tip of the strum to the tip of the telson, excluding uropods) and ight measurements are plotted on logarithmic co-ordites. The relationship was expressed by the equations:

$$\log_{10}TL = 1.68 + 0.31 \log_{10}W$$

d

$$\log_{10}W = -5.43 + 3.23 \log_{10}TL,$$

ere TL=total length in mm and W=live weight in g. dditional measurements were made on 66 of the animals d showed the relationship between carapace length, both th and without the rostrum, and total length. These are own in Figure 10. The following equations described the



g. 9. The relationship between total length and live weight of *Macrochium rosenbergii*. The regression line of length on weight is drawn.

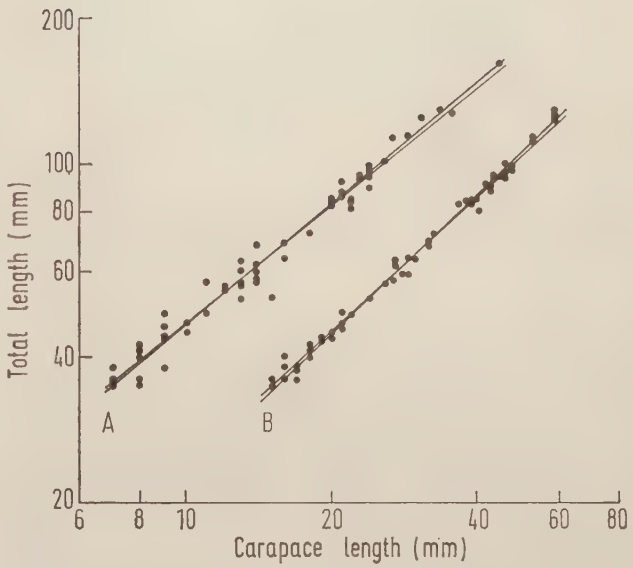


Fig. 10. The relationship between carapace length and total length of *Macrobrachium rosenbergii*. The calculated regression lines are drawn. In line A the carapace was measured from the posterior margin of the orbit to the posterior mid-dorsal edge of the carapace. In line B the data include the length of the rostrum.

relation of carapace length (measured from the posterior margin of the orbit to the posterior mid-dorsal edge of the carapace) to total length (Figure 10, line A):

$$\log_{10}TL = 0.86 + 0.81 \log_{10}CL$$

$$\log_{10}CL = -1.02 + 1.21 \log_{10}TL,$$

and the relation of carapace length (including the rostrum) to total length (Figure 10, line B):

$$\log_{10}TL = 0.44 + 0.93 \log_{10}RCL$$

$$\log_{10}RCL = -0.46 + 1.06 \log_{10}TL,$$

where TL=total length in mm; CL=carapace length in mm, and RCL=carapace length including rostrum in mm.

The relative size of the carapace increased as the prawns grew, that is to say, the carapace was positively allometric in respect to the body as a whole. However, the length of the rostrum was negatively allometric relative to the carapace:

$$\log_{10}R = 0.32 + 0.72 \log_{10}CL,$$

where R=length of rostrum in mm (RCL–CL).

Salinity

The larvae of *M. rosenbergii* require brackish water (5‰–26‰ salinity) in order to complete their development. After metamorphosis, post-larvae in their natural environment usually remain in brackish water for one to two weeks before they migrate to fresh water (Ling 1969a).

The effect of a reduction of salinity on growth was measured in two experiments when post-larvae were cultured in water of either 15‰ or 2‰. Before the experiments were started, newly metamorphosed post-larvae were weaned over a nine day period from a diet of *Artemia* to a diet of *Mytilus* flesh, in water of 15‰ salinity. They were

TABLE 8 *The effect of a decrease in salinity on the growth of* Macrobrachium rosenbergii *post-larvae. The experimental groups were cultured at a salinity of 15‰ for the first week and thereafter at 2‰. The control groups remained at 15‰ throughout. Each group contained eight animals*

	Experiment 1		Experiment 2	
	Control	Experimental	Control	Experimental
Initial mean weight (mg)	34.4	32.5	32.2	34.3
Mean weight (mg) after:				
1 week	38.6	40.0	36.3	37.7
2 weeks	43.8	49.6	42.5	45.1
3 weeks	55.6	94.5*	54.7	80.1
4 weeks	57.1	115.6*	57.2	99.8*

* Denotes that the mean was significantly different from that of the controls ($P < 0.05$).

then divided into two groups of eight prawns and cultured individually in polystyrene containers for one week at a salinity of 15‰. After this, one group of eight individuals was transferred to water of 2‰ salinity for a further three weeks while the other remained at 15‰. Each week the prawns were weighed. The results of the two trials are given in Table 8 and have been combined for illustration in Figure 11. The control groups showed an increase in mean weight from 33 to 57 mg in four weeks, while the experimental prawns grew from 33 to 108 mg. The results highlighted the marked effect of a reduction of salinity on the growth of this species.

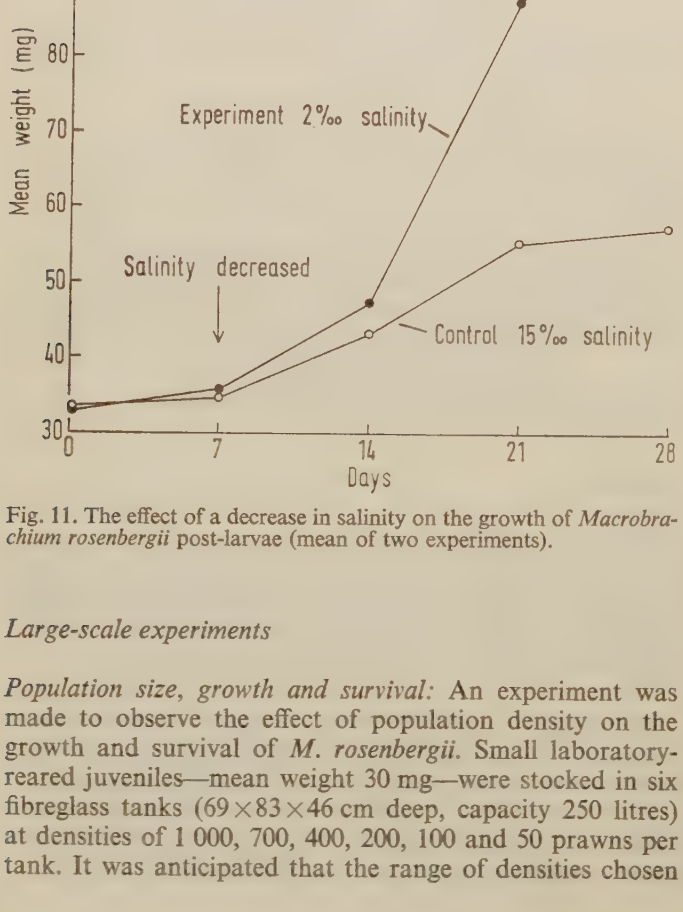


Fig. 11. The effect of a decrease in salinity on the growth of *Macrobrachium rosenbergii* post-larvae (mean of two experiments).

Large-scale experiments

Population size, growth and survival: An experiment was made to observe the effect of population density on the growth and survival of *M. rosenbergii*. Small laboratory-reared juveniles—mean weight 30 mg—were stocked in six fibreglass tanks (69 × 83 × 46 cm deep, capacity 250 litres) at densities of 1 000, 700, 400, 200, 100 and 50 prawns per tank. It was anticipated that the range of densities chosen would also quickly reveal some of the problems peculiar to the intensive culture of prawns in indoor systems.

Each tank was shaded from direct light and contained four vertical sheets (30 × 75 cm) of plastic 5 mm mesh suspended in the water. This encouraged an even distribution of prawns throughout the available volume of water. Water was recirculated to each tank from a common reservoir after it was heated to 28 ± 1°C by an immersion heater. The total capacity of the system was initially 2 200 litres but was increased to 2 800 litres 41 days after the experiment was started. At this time a trickle filter of pebbles and oyster shell was also incorporated.

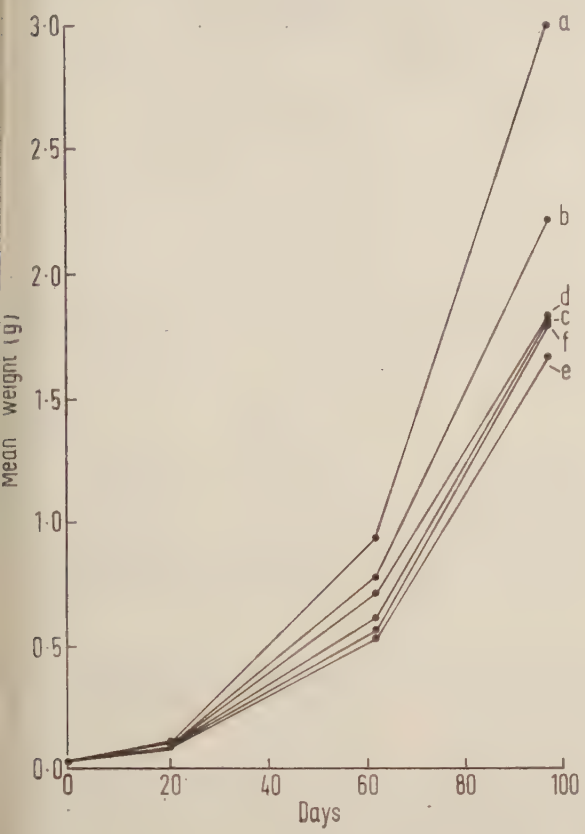
Each day approximately 100 litres of water were replaced with fresh tap water—which was adjusted to about 2‰ salinity—and each month the tanks and pipework were thoroughly cleaned. Fresh mussel was supplied twice daily as food, and at the same time uneaten food and detritus were removed by siphoning.

The experiment was curtailed after 97 days when heavy mortalities—76 per cent died—followed an overnight failure of the laboratory supply of compressed air. Apparently the rate of water exchange in the tanks (2.4–2.8 litres per min) was not sufficient to cope with the high oxygen demand of the large populations without auxiliary aeration. Notable exceptions were the populations of 50 and 100 prawns. The numbers found were:

	Initial population size					
	1 000	700	400	200	100	50
Total number that remained	217	202	156	156	80	43
Number of live prawns	4	5	49	21	80	43

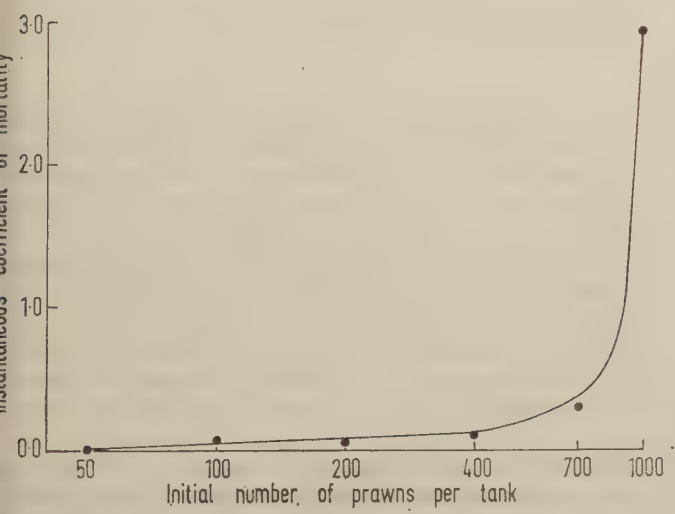
These figures were only approximate, since about 20 prawns had climbed out of the tanks during the night and it was impossible to say from which groups they had come. Further deaths occurred in the next 48 hours despite improved oxygen levels.

Figure 12 shows the increase in mean weight of the prawns after three months. The final values—at day 97—were estimated from length measurements of dead prawns. The greatest increase occurred in the 50 and 100 populations and was from 30 mg to 3.0 and 2.2 g respectively. The others grew to 1.7–1.8 g mean weight.



g. 12. The growth of *Macrobrachium rosenbergii* juveniles in popula-ons of different sizes: curve a, 50 per tank; b, 100; c, 200; d, 400; e, 0; f, 1 000.

The size distributions in the populations after 62 and 97 ays are shown in Figure 13. When the experiment started ie prawns were normally distributed and 96 per cent were etween 11 and 20 mm total length. After 97 days of growth ie size ranges were similar in each population and spread om 24 to 123 mm. A significant positive skew had deve-ped in the distribution of those originally containing 000, 700 and 400 prawns ($P < 0.05$)—the third moment bout each mean divided by the cube of the appropriate andard deviation gave 0.82, 0.77 and 0.88 respectively—nd approximately 7 per cent of all the prawns weighed ore than 5 g.



g. 14. The relation between population size and mortality after 62 ys in juvenile *Macrobrachium rosenbergii*.

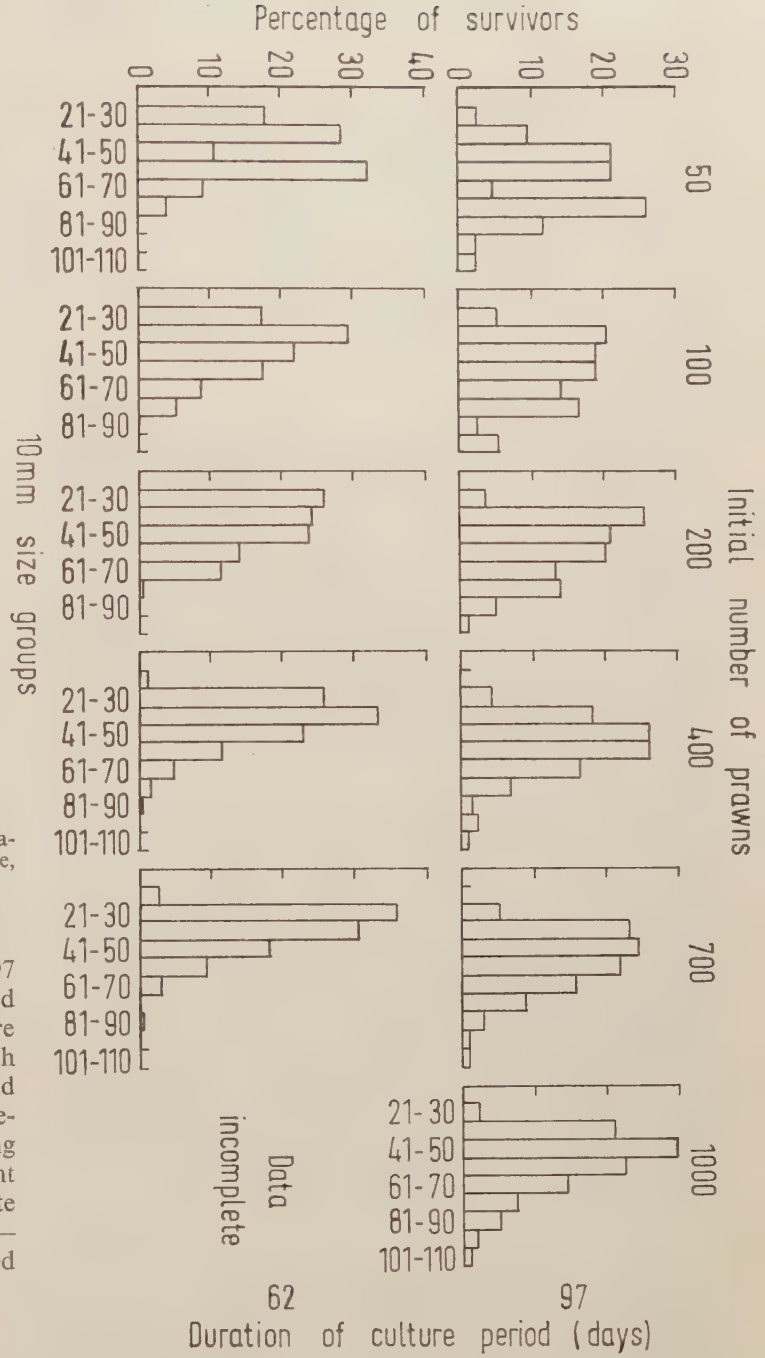


Fig. 13. The size distribution of the survivors in populations of juvenile *Macrobrachium rosenbergii* after two and three months of culture. Each discrete width of horizontal scale corresponds to a 10 mm size group, and the first such width of scale for each population represents the size group 11–20 mm.

The natural mortality in the tanks over the first 62 days of the experiment is expressed in Figure 14 as the relationship between the initial stocking density and the instantaneous coefficient of mortality (Z). The value of Z was obtained from:

$$N_t = N_o^{e-Zt}$$ Beverton and Holt (1956)

where N_t=number of prawns surviving after time t, N_o= initial number of prawns, Z=instantaneous coefficient of mortality and t=time interval between measurements (62 days). The data, plotted on a logarithmic co-ordinate, showed how mortality increased in relation to an increase in the population density. The greatest single cause of mortality during this period was probably cannibalism, since partially eaten, newly moulted specimens were often found.

TABLE 9 *The increase in biomass of populations of* Macrobrachium rosenbergii *cultured at different densities for three months in 250 litre fibreglass tanks (69 × 83 × 46 cm deep)*

Initial population size (number per tank)	Weight of seed prawns (g)	Weight of prawns (g) produced per m² of tank floor	Weight of prawns (g) produced per g of seed per m² of tank floor
1 000	30.3	684.5	22.6
700	21.2	588.4	27.7
400	12.1	499.4	41.3
200	6.1	494.1	81.0
100	3.0	310.8	103.6
50	1.5	227.0	151.3

The total weight of prawns produced in the system amounted to 1 606 g from 74.2 g of seed stock. In Table 9 the production rates of each tank are compared. The units of production were expressed as the total weight of prawns produced per m² of tank floor area and also the weight of prawns produced per g of seed stock per m² of tank floor area. The weight of prawns per unit area increased—to a maximum of 684 g per m²—as the population density increased, but production efficiency—related to the initial weight of seed stock—increased as the population size decreased. Production was greatest in the population of 50 prawns, where each g of seed produced 151 g after three months.

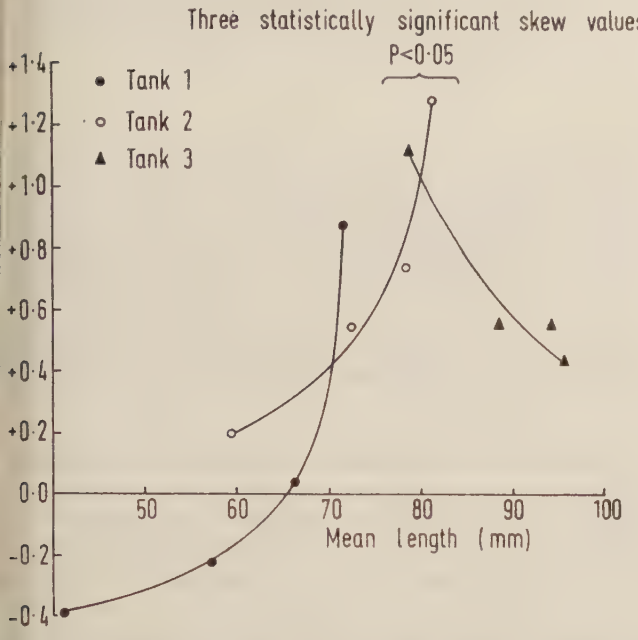
Growth to marketable size: The survivors of the previous experiment were divided into three size groups (25–50 mm, 58 prawns; 51–70 mm, 71 prawns; and 71–75 mm, 50 prawns) and cultured separately for a further three months. They were kept under the same experimental conditions as before and observations were made on their growth, survival and distribution of sizes. The mean growth rates are compared in Figure 15, where the slopes show a similar rate of increase for each group. The survival rates over the three months (63 per cent, on average) were encouraging and are also shown in Figure 15. The discrepancy in the survival results of tank 3 was due to the accidental introduction of two prawns from one of the other tanks.

Fig. 15. The survival (above) and growth (below) of *Macrobrachium rosenbergii*.

Fig. 16. The change of size distribution in three populations of *Macrobrachium rosenbergii* cultured for 85 days.

The changes that occurred in the size distribution in each group as the prawns grew are represented by the histograms in Figure 16. In Figure 17 the degree of skewness—the third moment about the mean divided by the cube of the standard deviation—is plotted against the mean length and shows that in tanks 1 and 2 there was a progressive trend towards a positive skew in the distribution as a proportion of the prawns grew more rapidly than the others. In tank 3, however, where the distribution was initially skewed in a positive direction, there was a trend towards a normal distribution, as if the growth rate of the largest prawns had decreased.

Values of the third moment greater than +0.7 indicated distributions that were significantly different from normal in tanks 2 and 3 ($P < 0.05$) but all other values were not. However, if the trends shown were real, the most likely cause



g. 17. The degree of skewness of the size distribution in three popula-ns of *Macrobrachium rosenbergii*. The curves were fitted by eye.

ould be that some environmental factor—for example, vailable space or food—inhibited the growth of the largest rawns. Indications that space was limiting were obtained hen large specimens were seen with ulcer-like wounds on e third abdominal tergite. It was thought that damage as caused when prawns employed their "tail-flick" escape anoeuvre and crashed backwards into the vertical sheets plastic hanging in the tanks. Repeated collisions with ese "spacers" kept the wounds open but they healed after -3 moults when the prawns were kept undisturbed in bare nks.

When the experiment ended, 40 of the 112 survivors were saleable size (8 g) and some of these were used as breeding ock.

Reproduction

Maturation and spawning of *M. rosenbergii* was observed among approximately 30 laboratory-reared prawns kept separately in white polythene tanks of 25 or 50 litres capacity. The tanks received a flow of warm brackish water (5‰ salinity and 28 ± 1°C) from a 400 litre reservoir, and pieces of *Mytilus* flesh were given daily as food. The prawns were inspected each day and a male was placed in the tank of any ripe female that had moulted within the past 24 hours—ripe females were recognized by the presence of the prominent orange gonads visible through the dorsal and lateral areas of the carapace. After a period of 1–4 hours (usually 1 hour) the male was removed and a subsequent periodical check was made on the viability of any eggs that were produced. Unsuccessful matings usually resulted in the abortion of the eggs within ten days.

The smallest female to spawn was also the smallest to produce viable larvae and measured 128 mm total length; the smallest male to function was 145 mm total length. One male (191 mm) fertilized 7 females within two intermoult periods—34 and 98 days respectively—and each brood of eggs hatched live larvae after an incubation period of 19–21 days. Two females each produced two broods of larvae within 38 days. These preliminary results confirmed the observations of Rao (1967) and Ling (1969a), and showed that there were no inherent difficulties in rearing and maintaining a breeding stock of *M. rosenbergii* in a closed water system.

Discussion

The results reported in this paper describe how two foreign species of prawn—*P. platyceros* and *M. rosenbergii*—were brought to Britain and cultured to an edible size in captivity. They define broadly the environmental conditions in which the prawns were able to survive, and indicate some of the more important factors that influence their growth.

The species studied were selected to test their suitability for two methods of commercial culture that seemed feasible in the U.K. The methods envisaged involved (a) culture in open ponds or tanks with usually only small amounts of temperature control, and (b) culture in intensive systems indoors with maximum control of the environment. To operate a pond culture system in the U.K. it is believed that at least one main crop a year must be obtained. *Palaemon serratus*, the only endemic species suitable for cultivation, does not grow sufficiently fast (Forster 1970a, Wickins 1972), but the results of this study show that *Pandalus platyceros* can achieve very creditable growth rates and intimate that a marketable size might be attained in one growing season. One particular problem with *P. platyceros* that was revealed, however, is the difficulty of maintaining a breeding population. Butler (1970) found no evidence to suggest that *P. platyceros* breeds more than once a year and suggests that few of the females—at least in the area around Vancouver Island—breed more than once in their lives. Signs of sex reversal in year-old cultured prawns and regeneration of the spent gonads of imported females were absent from the prawns used in the present work. The problem would be circumvented if a reliable supply of seed could be imported cheaply for each growing season or obtained from ovarian tissue cultured *in vitro* (Oyama and Kamemoto 1970).

It is thought that prawn culture in a controlled environment indoor system would require three to four crops each year to be commercially viable. The investigations reported here show that *M. rosenbergii*—which, by virtue of its growth rate has the potential to achieve this—can be cultured through a complete life-cycle in a closed water system. Very little detailed information on the growth rate of prawns cultured in dense populations was obtained although in these experiments they reached a commercially acceptable size in six months.

The economic culture of tropical prawns in the United Kingdom would involve the use of recirculated water, and the results of the present trials drew attention to some of the problems associated with the re-use of water in such systems. A high degree of turbidity was caused by suspended food and faecal material in the water, and although no measurements were made it was probable that waste metabolites were also present. This meant that substantial aeration in the cultures was necessary to maintain the dissolved oxygen at a suitable concentration. Apart from one occasion—when the aeration system failed—the levels of dissolved oxygen were sublethal; pollutants, too, must have been at a relatively low level. The stresses to which the prawns were subjected by sublethal concentrations of waste materials and dissolved oxygen, and their effect on growth and behaviour, may have been considerable.

Fujimura and Okamoto (1970) postulated that juvenile *M. rosenbergii* reared in tanks without suitable shade and shelter—which was usually provided by growths of wat hyacinth—suffered high mortalities and a greater proportio of them were crippled by fighting because of competitio for territories in the limited areas of shade. The aggressi nature and large chelae of *M. rosenbergii* might not favourable attributes for intensive cultivation, and for th reason some penaeid species with similar growth rates—f example *Penaeus monodon* Fabricius, *P. orientalis* Kish nouye—would seem to be worth investigation.

The selection of an exotic species of prawn for culture Britain must also involve a consideration of its ability mature and reproduce in captivity, particularly if th vagaries of natural supplies of seed prawns are to be avoide *M. rosenbergii* breeds readily in captivity, and specime taken to Hawaii—where the species is not naturally endem —have been cultured through as many as nine generatio (Fujimura and Okamoto 1970). However, warm-wat prawns of the penaeid family—many of which also hav considerable potential for intensive culture in Britain—d not mature readily under artificial conditions (Wheele 1970). Specific representatives of this group are *Penaeu japonicus* Bate, *P. aztecus* Ives, *P. duorarum* Burkenroad an *P. setiferus* (Linnaeus); and it is the females in particula that fail to ripen, although possible exceptions are thos cultured in large ponds (Hughes, D. A., pers. comm.).

cknowledgements

am particularly grateful to Dr T. H. Butler and Mr tes of the Fisheries Research Board of Canada, Na- imo, British Columbia, for consignments of live *Pandalus tyceros*, and to Dr T. Fujimura of the Bureau of Com- rcial Fisheries, Honolulu, Hawaii, and Mr K. C. Camp- l for specimens of *Macrobrachium rosenbergii*.

t is also a pleasure to thank T. W. Beard and G. Williams their assistance in this work.

References

ANDERSON, J. I. W. and CONROY, D. A., 1968. The significance of disease in preliminary attempts to raise Crustacea in sea water. *Bull. Off. int. Epizoot.*, **69** (7–8), 1239–1247.

BERKELEY, A. A., 1930. The post-embryonic development of the common pandalids of British Columbia. *Contr. Can. Biol. Fish.*, **6** (6), 79–163.

BEVERTON, R. J. H. and HOLT, S. J., 1956. A review of methods for estimating mortality rates in exploited fish populations, with special reference to sources of bias in catch sampling. *Rapp. P.–v. Réun. Cons. perm. int. Explor. Mer*, **140,** pt. 1, 67–83.

BOOKHOUT, C. G. and COSTLOW, J. D., Jr, 1970. Nutritional effects of *Artemia* from different locations on larval development of crabs. *Helgoländer wiss. Meeresunters.*, **20,** 435–442.

BROAD, A. C. and HUBSCHMAN, J. H., 1963. The larval development of *Palaemonetes kadiakensis* M. J. Rathbun in the laboratory. *Trans. Am. Microsc. Soc.*, **82** (2), 185–197.

BUTLER, T. H., 1964. Growth, reproduction, and distribution of pandalid shrimps in British Columbia. *J. Fish. Res. Bd Can.*, **21,** 1403–52.

BUTLER, T. H., 1970. Synopsis of biological data on the prawn *Pandalus platyceros* Brandt, 1851. *Fish. Rep. FAO*, No. 57, Vol. 4, 1289–1315.

COLE, H. A. and MISTAKIDIS, M. N., 1953. A device for the quick and accurate measurement of carapace length in prawns and shrimps. *J. Cons. perm. int. Explor. Mer.*, **19,** 77–79.

FORSTER, J. R. M., 1970*a*. Further studies on the culture of the prawn, *Palaemon serratus* Pennant, with emphasis on the post-larval stages. *Fishery Invest., Lond.*, Ser. 2, **26** (6), 40 pp.

FORSTER, J. R. M., 1970*b*. Studies on the development of a compounded diet for prawns with particular reference to *Palaemon serratus* P. *Ph.D. Thesis, University College of North Wales.*

FUJIMURA, T., 1966. Notes on the development of a practical mass culturing technique of the giant prawn *Macrobrachium rosenbergii. Proc. Indo–Pacif. Fish. Coun.*, 12th Session, Honolulu, Hawaii, USA. IPFC/C66/WP47, 4 pp. (mimeo).

FUJIMURA, T. and OKAMOTO, H., 1970. Notes on progress made in developing a mass culturing technique for *Macrobrachium rosenbergii* in Hawaii. *Proc. Indo–Pacif. Fish. Coun.*, 14th Session, Bangkok, Thailand. IPFC/C70/SYM53, 17 pp. (mimeo).

HUBSCHMAN, J. H. and ROSE, J. A., 1969. *Palaemonetes kadiakensis* Rathbun: post embryonic growth in the laboratory (Decapoda, Palaemonidae). *Crustaceana*, **16** (1), 81–87.

LEWIS, J. B., and WARD, J., 1965. Developmental stages of the palaemonid shrimp *Macrobrachium carcinus* (Linnaeus, 1758). *Crustaceana*, **9** (2), 137–148.

LING, S. W., 1969*a*. The general biology and development of *Macrobrachium rosenbergii* (de Man). *Fish. Rep. FAO*, No. 57, Vol. 3, 589–606.

LING, S. W., 1969*b*. Methods of rearing and culturing *Macrobrachium rosenbergii* (de Man). *Fish. Rep. FAO*, No. 57, Vol. 3, 607–619.

LITTLE, G., 1969. The larval development of the shrimp, *Palaemon macrodactylus* Rathbun, reared in the laboratory, and the effect of eyestalk extirpation on development. *Crustaceana*, **17** (1), 69–87.

MISTAKIDIS, M. N. (Ed.), 1968–1970. Proceedings of t World Scientific Conference on the Biology and Cultu of Shrimps and Prawns. Mexico City, June 1967. *Fi Rep. FAO*, No. 57, Vols. 1–4.

OYAMA, S. N. and KAMEMOTO, F. I., 1970. Organ culture crab ovaries. *Crustaceana*, **18** (3), 309–311.

PANIKKAR, N. K., 1968. Osmotic behaviour of shrimps a prawns in relation to their biology and culture. *Fish. Re FAO*, No. 57, Vol. 2, 527–538.

PRICE, V. A. and CHEW, K. K., 1969. Shrimp larval cultu Contr. Univ. *Wash. College (Sch.) Fish.*, No. 300, p. 4

RAO, R. M., 1967. Studies on the biology of *Macrobrachiu rosenbergii* (de Man) of the Hooghly estuary with not on its fishery. *Proc. natn. Inst. Sci. India*, **33**B (5 and 252–279.

REEVE, M. R., 1969. The laboratory culture of the praw *Palaemon serratus. Fishery Invest., Lond.*, Ser. 2, **26** (1 38 pp.

REGNAULT, M., 1969. Influence de la température et l'origine de l'eau de mer sur le développement larvaire laboratoire d'*Hippolyte inermis* Leach. (Décapode–Nata tia). *Vie Milieu*, Ser. A, **20** (1–A), 137–152.

RYTHER, J. H. and BARDACH, J. E., 1968. The status an potential of aquaculture, particularly invertebrate and alga culture. Vol. 1, Parts 1 and 2. *US Dept. of Commerc National Bureau of Standards, Institute for Applied Tec nology*, Rept No. PB 177, 767, 261 pp. Reproduced b Clearinghouse, Springfield, Va. 22151, USA.

UNO, Y. and KWON, C. S., 1969. Larval development *Macrobrachium rosenbergii* (de Man) reared in the labora tory. *J. Tokyo Univ. Fish.*, **55** (2), 179–190. (13 plates).

WALNE, P. R., 1958. The importance of bacteria in labora tory experiments on rearing the larvae of *Ostrea edul* (L.). *J. mar. biol. Ass. UK*, **37,** 415–425.

WHEELER, R. S., 1970. Culture of juvenile and adult shrimp *Circ. Fish Wildl. Serv. Wash.*, (343), 9–10.

WICKINS, J. F., 1969. Preliminary experiments in the cultu of the prawn *Pandalus platyceros* (Brandt) and the giar prawn *Macrobrachium rosenbergii* (de Man). *ICES CM 1969*/E:11, 8 pp. (mimeo).

WICKINS, J. F., 1970. The food value of the brine shrim (*Artemia salina* L.) to larvae of the prawn (*Palaemo serratus* Pennant). *ICES CM 1970*/E:6, 8 pp. (mimeo).

WICKINS, J. F., 1972. On the laboratory culture of th common prawn *Palaemon serratus* Pennant. *Fisher Invest., Lond.*, Ser. 2, **27** (4) 23 pp.

PENDIX I *Experimental tank sizes and yields of cultured populations of* Pandalus platyceros. *Populations A, D and C were in recirculated sea water; populations C1 and C2 were in flowing-through sea water*

	Population				
	A	D	C (mean of four)	C1	C2
: of culture vessel (cm)	69×83×46 deep	69×83×46 deep	63×55×61 deep	122×122×30 deep	122×122×30 deep
mber of prawns per m² ank floor area	49	165	185	50	99
ditional surface area (m²) : Methods)	0.9	–	0.5	–	–
an % survival at a mean ght of 4 g	50	36	83	86	73
an final weight (g)	8.0	4.0	5.0	5.3	4.6
al yield of prawns (g) m² of tank floor	42	238	492	213	306
ration of trial (days)	200	160	160	190	190

Printed in England for Her Majesty's Stationery Office by W. A. SMITH (Leeds) LTD.
Dd 502643 K8 8/72